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# DEVELOPMENT OF TEST METHODS FOR THE ELECTROSTATIC PROPERTIES OF NONHOMOGENEOUS FABRICS: PHASE I



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This report covers phase I of a project initiated for the purpose of establishing the feasibility of testing for the electrostatic charge decay rates, field-suppression capabilities, and triboelectric charge-generating properties of textiles which contain conductive filaments. Existing test equipment was modified to facilitate the collection of test data normally obscured by the field-suppression effect inherent in nonhomogeneous materials. A triboelectric test fixture was designed and fabricated to enable the measurement of peak voltages generated on a fabric when rubbed by itself or other selected materials. This apparatus is designed for use in conjuction with the modified test equipment and other appropriate peripherals as a system. This effort has resulted in the capability of performing tests which will determine (a) The decay rates of the nonconductive content of a fabric; (b) The percentage of field-suppression offered by the conductive content of the fabric, and (c) The ability of a fabric to attain a charge during the rubbing process.

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## PREFACE

The October 1984 issue of "Department of Defense Program Solicitation for Small Business Innovation Research No. 85.1" included Army Research Topic No. 83, "Test Methodology and Apparatus for Measurement of Static Electricity in Fabrics" submitted by U.S. Army Natick Research and Development Center. The stated purpose of the proposed exploratory development effort was to devise suitable test methods and apparatus for the measurement of the electrostatic properties of synthetic fabrics which incorporate a small percentage of highly conductive material. These fabrics are intended for use in the manufacture of uniforms for Combat Vehicle crewmen and aircrewmen to minimize the generation of electrostatic charges.

A background of considerable research into the properties of synthetic clean-room garments containing conductive fibers prompted I.K.E. Associates, Inc. to respond to the solicitation. Government contract No. DAAK60-85-C-0074 was subsequently awarded. Sharyn Seasholtz (STRNC-ITC), U.S. Army Natick was appointed Project Officer. Work commenced on the project on 1 July 1985.

Existing commercially available test equipments were obtained and modified as necessary to test for the static decay and field suppression properties of the fabrics in question. A triboelectric test apparatus was designed and fabricated to determine the charge generating property of a fabric when rubbed by the same or a different material. The apparatus utilizes the above test equipment to display and record the data obtained.

I.K.E. Associates, Inc. would like to thank Mr. William Moore and Mr. David Moore of Custom Models, Inc., Indianapolis for their valuable contributions in producing the triboelectric test apparatus and other necessary items from a minimum of information.

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FINAL REPORT
DEVELOPMENT OF TEST METHODS
FOR THE ELECTROSTATIC PROPERTIES
OF NONHOMOGENEOUS FABRICS: PHASE I

## 1. BACKGROUND:

The hazard presented by an electrostatic discharge in an explosive environment has been well known for many years. The prevalence of highly (electrically) insulative synthetics in garments and other commonly used items has increased the incidence of such discharges to unprecedented proportions. The problem has expanded from explosive hazards into the world of microelectronics where sensitive devices can experience catastrophic damage from discharges so small in amplitude as to be undetectable by normal human senses. Moreover, a static charge residing on the surface of a highly insulative material can induce a charge on nearby conductive items. This phenomenon has been known to initiate explosions without the need for an actual discharge by actuating electrical "squib" type firing devices with fatal results.

The problems are of such magnitude that they have resulted in the establishment of an entirely new industry, that of designing and supplying materials and equipment for the specific purpose of controlling the generation of static charges, or of minimizing their harmful effects. The proliferation of special materials in a myriad of forms has far outstripped the generation of test methods suitable for determining their ability to perform as intended. As a result, the manufacturers and/or purveyors of these items rely to a great extent on a very few already existing test methods as references to describe the electrical characteristics of the materials in question. In many instances, the test methods referenced were never designed to test that particular material (or form) and it remains a mystery how the published data was obtained.

One such family of specialized materials is a new type of textile which incorporates conductive carbon or metal filaments in various patterns and percentages. These textiles are intended for use in the manufacture of garments to be worn in explosive environments such as hospital operating rooms and munitions handling situations, and in areas where microelectronic devices are being fabricated. These unique fabrics are intended to furnish two forms of electrostatic protection:

(a) The conductive filaments provide an extremely low resistance path from all areas of the garment to a ground connection in order to bleed off a charge more rapidly than it can accumulate, and

(b) These same filaments (when grounded) provide a shielding effect which suppresses any voltage fields emanating from charges that may be present on garments worn beneath.

This shielding effect, although extremely desirable, has the distinct disadvantage of confusing the results of any tests performed in accordance with existing standardized test methods. It is necessary, therefore, to either devise new test methods for these fabrics, or to modify existing test methods to the extent that they are usable for the electrical characterization of the materials in question. Thus, appropriate accept/reject criteria can be established.

## 2. INTRODUCTION:

Phase I of this project was initiated on 1 July 1985 under Contract Number DAAK60-85-C-0074. Its basic purpose was to establish, if possible, the feasibility of testing for the charge decay rates, electrostatic field-suppression capabilities, and triboelectric charge generating properties of a variety of textiles. These textiles are under consideration for the manufacture of military uniforms intended for use in explosive environments. The fabrics are unique in that they are a blend of the synthetics known as NOMEX® and KEVLAR® with small percentages of stainless steel, silver, or carbon intended to increase electrical conductivity. It was originally assumed that these percentages of conductors were in the form of conductive yarns interwoven with purely synthetic yarns. It was later established that every yarn in each fabric consisted of a conglomerate of the two synthetic resins plus one of the three conductive materials, all assumed to be in the percentages indicated in information provided by the manufacturer.

Incidental to the above feasibility study was the need to modify available commercial test equipment in order that data the equipment was not designed to provide could be obtained. Further, it was necessary to design a completely new triboelectric test fixture capable of establishing the peak value of electrostatic charge which could be generated on a specimen when rubbed by the same or by another selected material. The most important criteria for this design were (1) repeatability of test results established by electrical automation in order to avoid the insertion of unpredictable human errors into the collected test data, and (2) the accurate documentation of critical physical dimensions to assure identical charge force-fields in duplicate test fixtures.

## 3. TEST EQUIPMENT:

The following commercially available test equipment was acquired for use in the performance of this project:

(a) Electro-Tech Systems, Inc. (ETS) Model 506 Controlled Humidity Test Chamber.

(b) ETS Model 406C Static Decay Meter.

(c) BBC-Metrawatt/Goerz (BBC) Model M-2050 Digital Scope-Multimeter.

(d) BBC Model SE-120 Chart Recorder.

(e) Solomat Corporation Model MPM 500 Thermo-Hygro-Tachometer.

In addition to the above, a triboelectric test fixture has been designed and fabricated. This apparatus operates in conjunction with (b) and (d) above.

## 4. TEST EQUIPMENT MODIFICATIONS:

Commercially available test equipments were modified for purposes of this project as follows:

### 4.1 MODEL 506

The humidity test chamber has been modified as follows to improve its capabilities.

(a) An ionizing system has been installed within the chamber to neutralize any residual charges present that might distort the data obtained during tests. This unit is completely contained within the chamber so that only the internal atmosphere is circulated.

(b) Provisions have been made for the insertion of the MPM 500 temperature humidity probe into the wall of the chamber while maintaining hermeticity.

(c) A system of hermetic electrical feed-thru connectors has been installed in the chamber wall to facilitate the connection of control and instrumentation equipment to any test apparatus that might be placed within the controlled environment.

These modifications resulted in maximum working space within the chamber. Further, tests have shown that the chamber is capable of reducing its internal RH level to less than 1% in a very reasonable length of time without the use of dry nitrogen.

### 4.2 MODEL 406C:

The Model 406C has been modified to improve its accuracy and broaden its capabilities as follows:

(a) The specimen mounting plate of the decay time test fixture was redesigned to present a surface of maximum uniformity to the specimen under test. The consequent reduction of spacing between the detector probe and specimen was found to have lowered the field-suppression effects of the specimen electrodes from 30% to 25.5%. The addition of grounded shields between the electrodes and the probe window further reduced these effects to about 15%.

Since such effects from all possible sources have been found to be superimposed with the strongest suppression predominating, this has resulted in the capability of detecting any field-suppression effect inherent in the specimen which is measurably in excess of 15%.

(b) The specimen charge and discharge relays together with their drive-signal filter circuits have been relocated from the measuring instrument into the base of the test fixture. This action has shortened the discharge path from about ten feet to a few inches. This has eliminated a significant amount of capacitance which was uncontrollable due to possible inadvertent changes in the lead dress of interconnecting cables. Incidental to this change was the removal of a 10-MΩ resistor from the discharge path. The original purpose of this resistor was to limit the discharge current to a slower rate to avoid undesirable radiated pulse interference with the instrument's front-panel timing circuitry. Since the entire discharge path is now located within shielded portions of the test fixture, this function is no longer necessary. The resistor was relocated within the instrument to serve as a high-voltage (HV) current-limiter for personnel safety.

Because the above-mentioned capacitance was in parallel with that of the specimen, and the 10-MΩ resistance was in series with that of the specimen, their resistance-capacitance (RC) time constant was additive to the decay rates of all specimens tested. This added time was formerly included in all decay measurements taken, whether by front-panel readout or by recording instrument. The net result of this added time was a significant error inherent in the equipment which was usually somewhat unpredictable due to possible changes in the capacitance value C in the formula $t = RC$.

This charge/discharge circuit modification also included the relocation of a 100-MΩ resistor formerly used for HV supply current-limiting. The resistor is now in the base of the test fixture and in series with the HV supply side of the charge relay. Its new function is to maintain the HV supply interconnect cable at the set level at all times. This prevents possible radiated interference with instrumentation external to the test fixture caused by grounding the specimen electrodes while the charge relay is closed.

(c) It was discovered that when the decay rates of specimens with very long decay times were being measured, the detector probe circuit would drift away from its zero calibration point. To avoid this situation, an auto-zero cycling circuit was added to the 406C. This circuit is front-panel controlled. Selected cycle periods are available for various recording chart speeds. The zero dwell-time of the circuit has been set to allow the chart pen to move entirely across the paper prior to commencing the return to its original position. By this means a zero level is indicated on the chart each time cycling occurs. This information is quite useful for later chart analysis.

(d) The 406C has an automatic "test-over" feature that stops the front-panel clock and returns the instrument to zero/standby conditions when the measured charge level arrives at a selected percentage of its original value. To prevent this from occurring while auto-zero cycling was in operation, a front-panel switch was added to inhibit the "test-over" function on demand. This inhibiting circuit is also quite useful when specimens with high field-suppression percentages are being tested, and for other tests not considered in the original design of the instrument.

(e) The instrument incorporates a circuit that automatically turns off the HV power supply if the test switch is not activated within three minutes after the charge cycle is initiated. This caused considerable inconvenience when charging a specimen that had a charge-up time in excess of that length of time Another circuit with a front panel switch was therefore installed to inhibit the three-minute shutdown feature at the operator's convenience.

(f) It was discovered that the measured charge signal available at the recorder output connector of the 406C was of opposite polarity to that indicated by the front-panel meter. This situation caused a considerable amount of confusion each time the system was assembled for operation with recording devices. Corrective action was taken by adding a unity-gain inverting amplifier in the recorder output curcuit. A rear-panel switch has been installed to allow selection of either polarity of output at the convenience of the operator. Also, a BNC coaxial connector has been placed on the rear-panel in parallel with the original DIN recorder output connector. This facilitates the application of a coaxial cable to a recording device when this is more convenient.

(g) Two paralleled trigger output connectors, one a banana jack and the other a BNC coaxial fitting, have been placed at the rear-panel of the instrument. Normally high (+3.7v), these go low upon activation of the specimen discharge relay. This signal is for use in initiating the sweep of a storage oscilloscope or other recording device.

(h) Other rear-panel connectors have been included to interface with an external control console and to facilitate remote control of recording devices.

The above modifications have made the 406C applicable for use in the special test procedures necessary for the measurement of the decay time and field-suppression properties of the fabrics in question. In addition, the accuracy of all decay time measurements performed have been considerably improved.

Finally, an entirely new application for the instrument has been introduced by the addition of the new triboelectric test fixture as an accessory. Details of that device will be discussed later in this section.

## 4.3 MEMORY CONDITIONER FOR MODEL M-2050:

It was discovered that the Model M-2050 had an offset from zero in its memory output. This situation caused difficulties in correlating scope indications with recordings made on the SE-120 chart recorder. It also resulted in the inability to utilize the full available width of chart paper to depict decay curves.

To correct these discrepancies, an adjustable offset and amplifier circuit was designed and installed in the test console. This circuit can now be connected between the memory output of the M-2050 and the input of a chart recorder to align the zero settings of the two instruments and allow an increase in signal amplification to the full width of the chart paper. The circuit is intended for use when measured decay rates are faster than the slew-rate capabilities of the recorder pen and the memory of the M-2050 must be utilized to slow the measured signal to a reasonable speed. The time required for the memory of the full width of the scope to be output is one minute, well within the capabilities of most chart recorders.

## 4.4 TRIBOELECTRIC TEST FIXTURE:

The triboelectric test fixture has been designed to fit easily within the test chamber. A small but powerful synchronous AC gearmotor with an output speed of exactly 100 RPM rotates a TEFLON® rubbing wheel. The rubbing surface of the wheel is mounted on a metal disk, which serves to suppress the field of the charge on the wheel once it has been removed from the specimen, thereby minimizing any distortion of the specimen field during measurement. The specimen is mounted between two metal plates, each of which incorporates a circular opening across which the specimen is stretched during the mounting procedure. Ten of these specimen holders are provided to facilitate the simultaneous conditioning of a number of specimens within the chamber.

One extra holder is provided for calibration purposes. This calibration module is physically identical to the specimen holders except for a permanent thin metal plate substituting for the specimen. Connecting 5,000 V DC obtained from the 406C to this module while installed in the test fixture allows the entire system to be calibrated for a maximum charge measurement of 25,000 volts.

After a specimen has been mounted in a holder and conditioned, the holder (with specimen) is carried to two slotted insulators and mounted between them. A momentary switch is then operated to initiate the timing sequence. This sequence causes a solenoid to operate, positioning the rotating wheel against the specimen. The wheel remains in that position for a fixed interval and is then automatically drawn back to its original position. Just prior to this last action, the chart paper commences to move and the pen is dropped onto the chart paper.

After another fixed interval, the chart stops moving, and the pen is lifted. The system is then ready for insertion of the next specimen holder. An "abort" switch is included so that the entire sequence can be halted at any time should something go wrong. Both "run" and "abort" switches are located on the test fixture with duplicate parallel switches located on the front panel of the control console.

The detector probe is so mounted as to measure the force-field emanating from the surface of the specimen opposite to that being rubbed. The measuring disk of the probe points at the exact center of the specimen from a distance of 0.75 inch. The metal specimen holder also becomes charged, either inductively in the case of highly insulative specimens, or directly when the specimen possesses some degree of conductivity. The holder thus also emanates a force-field, which contributes to the overall measurement. This is unavoidable but of no consequence provided all specimen holders are physically identical.

## 5. FABRIC TEST RESULTS:

Early in Phase I of the project it was discovered that contrary to the assumption that the fabrics in question incorporated a pattern of conductive filaments interwoven among purely synthetic yarns, every yarn consisted of a conglomerate of synthetic resins and a given percentage of conductive material. This caused considerable consternation until it was ascertained that this would have little or no effect on the test results.

Chart recordings made for the purpose of calculating percentages of field-suppression revealed that in one particular sample a considerable discrepancy existed. This material had been identified by the manufacturer as being composed of 95% Nomex, 4% Kevlar and 1% stainless steel. This was identical to the description provided for another fabric with the single exception that the second fabric had been imprinted with a camouflage pattern while the first was in its natural, undyed (greige) state. Chart recordings revealed that the greige material provided a field-suppression effect of less than 15%, the minimum detection level of the instrumentation (see 4.2.a). The dyed fabric identified as basically identical provided a field suppression effect of 82%, more in line with what might be expected. A record check was therefore initiated by the manufacturer.

This investigation revealed that the greige sample had been mistakenly identified as containing 1% stainless steel when in actuality NO conductive material was incorporated. This graphically illustrated the value of a field suppression test for ostensibly nonhomogeneous fabrics. Since the fabric in question is now known to consist of 95% Nomex and 5% Kevlar only --the basic synthetic content of all the fabrics under consideration-- this material will be used as the "control" for all future experiments involving decay rates and field suppression.

Tests have shown that when the factory-applied sizing finish has been removed from the fabrics under consideration, the materials are rendered highly insulative to the extent that a charge can be placed upon them merely by handling and cannot be removed except with great difficulty. By the same token, in this situation many minutes are required to deliberately place a known charge upon them by means of the instrumentation. To overcome this problem, an attempt was made to treat specimens with a topical antistat during a laundry process. This attempt was unsuccessful since little if any change in the electrical characteristics was noted.

A small quantity of the antistat was then mixed in reagent grade methyl alcohol. The specimens were thoroughly soaked in this solution and allowed to air-dry. Further testing revealed that the specimens had become highly conductive as evidenced by drastically reduced decay rates. The purpose of increasing the conductivity of the fabrics at that time was in the interests of more rapid evaluation of the proposed test methods. Since the fabrics tested in both instances consisted of stainless steel filaments completely surrounded by the synthetic resins mentioned earlier, it is evident that these materials are non-hygroscopic in nature, and that a solvent type carrier is needed to transfer the antistat into the molecular structure of the synthetic. This action will increase the volume conductivity of the synthetic to the extent that a charge current will then flow through the synthetic to the buried conductor and then follow this extremely low resistance path to ground.

After a decay-time chart has been recorded from a fabric utilizing Method 4046 of FTMS 101[1] for purposes of determining the percentage of field-suppression offered, the chart recorder can be set to a higher sensitivity such that the bottom of the voltage step will appear near the upper limits of the paper. The test is then repeated on the same specimen. This second chart is utilized to calculate the $\tau$ (tau) value of the purely synthetic content of the fabric utilizing the following formula:

$$\tau = \frac{(t^1 - t^2)}{\ln(V^2/V^1)} \qquad (1)$$

where:

$\tau$ is the decay rate in given increments of time,
$t^1$ is a selected time early on the exponential curve,
$t^2$ is some later time on the same curve,
$V^1$ is the voltage at $t^1$, and
$V^2$ is the voltage at $t^2$.

It is not necessary to know the actual voltages involved. The chart divisions between the recorded zero voltage and the selected points on the curve can be counted and these numbers substituted for the actual voltages with no change in calculated results. It is only necessary to know the time base of the recording and an accurate zero voltage reference for each of the two selected points on the curve.

The above formula (1) has been derived from the expression 1/e and defines the time necessary for the decaying exponential to arrive at 0.3678794412 (36.8%) of the voltage measured at $t^1$. The time necessary for a decaying exponential to arrive at zero (0.67% of the original value) for all practical purposes is $5\tau$. Thus, an entire decaying exponential can be defined merely by inserting appropriate values obtained from any portion of the curve into the formula (1) and then multiplying the result by 5. It is advisable, however, to extract the required data as early in the curve as practicable, since the ohmic values of many high-order polymers have been found to be voltage dependent to some extent, i.e. the higher the voltage, the lower the resistance. Selection of points very early in the curve should result in more consistent calculations.

These and other tests performed on the fabrics under consideration have established the feasibility of characterizing the electrical properties of nonhomogeneous fabrics and other similar materials whose field suppression effects are somewhat incomplete utilizing the procedures described.

Although the initial fabrication of the triboelectric test fixture was not completed until very late in the course of Phase I, and several minor discrepancies were noted, these have since been corrected. The first test actually performed with the fixture utilized a factory-fresh specimen of the control material described earlier. A controlled, ten-second rubbing time on the specimen resulted in a charge measurement of +22,500 volts, illustrating that the original theory is completely viable and that the system is indeed capable of measuring charges up to and including 25,000 volts. Further, it is entirely possible to reduce the amplification factor so that even higher values can be measured up to the point where arc-over would occur across the half-inch spacing between the specimen holder and system ground. Since the dielectric strength of air is about 75,000 volts per inch, it is theoretically possible to attain a charge of at least 35,000 volts on the sample holder before breakdown would occur.

## 5.1 EXPLANATIONS OF ILLUSTRATED CHARTS:

During experimental tests of fabrics performed to verify proper operation of the modified 406C and the triboelectric test fixture, a number of charts were recorded. Copies of these charts are included at the end of this report as Figures 1 through 13. All calculations for decay rates were performed utilizing formula (1) as stated earlier.

Figures 1 through 4 were recorded from the fabric discussed earlier, which was discovered to have no conductive content. Coded "NWNN", this fabric is now described as consisting of 95% Nomex and 5% Kevlar, with a Wickwell (water absorbent) finish. It has a natural (greige) color.

Figure 1 is a decay rate chart of a factory-fresh specimen with the sizing finish intact. A field-suppression effect of about 13% is evidenced by the straight line portion of the curve at the lower right. This effect can be considered entirely due to the physical attributes of the test fixture. The time base of the chart is 5 s/cm (vertical) while the amplitude is depicted horizontally with zero volts on the left and 5000 volts at full scale. This translates to 50 volts per small division. Voltages indicated at the two selected data points result in a $\tau$ value of 27.39 seconds with $5\tau$ then being about 137 seconds.

Figure 2 was recorded from the same material with the exception that this specimen had been lightly rinsed in perchlorethylene and allowed to air-dry. Note that this specimen has a slightly slower decay rate. It may be assumed that had this specimen been thoroughly dry-cleaned, it would have had an extremely slow decay rate.

Figure 3 is the chart of a specimen with all sizing removed and with no topical antistat treatment. Since at least as much time is required for a specimen to charge up as for it to discharge, this test was initiated at a charge level of 3450 volts. The time base is 1 min/cm. The indicated data points result in a $\tau$ of 6.7 minutes and a projected time to zero in excess of a half-hour.

Figure 4 was recorded from a specimen that had been treated with a topical antistat. The time base of this chart is 1 s/cm. Selected data points indicate a $\tau$ of 3.47 seconds and a $5\tau$ of 17.4 seconds. It would appear that the use of antistats on a routine basis would be a most useful procedure.

The charts in Figures 5 through 8 were recorded from specimens of a material encoded "SWKW" indicating that it is a Woodland camouflage printed fabric having a Wickwell water absorbent finish and 1% stainless steel conductor in a T-455 Nomex/Kevlar basic yarn. The presence of the conductors necessitated the use of the dual measurement procedure discussed earlier.

Figure 5 was recorded for the purpose of determining the amount of field suppression offered by the conductive content. This measurement indicated 88% suppression.

Figure 6 was obtained by overdriving the chart recorder by a factor of 10 and offsetting the zero level to be sure it would not drift off the paper. The time base is 5 s/cm and each small horizontal division is 5 volts. The specimen had been treated with a topical antistat and yielded a $\tau$ of 19.3 seconds and a $5\tau$ of 96.2 seconds.

Figure 7 was obtained in the same manner as Figure 5 utilizing a differently treated specimen of the same material. A field suppression effect of 91% was obtained which agrees rather closely with that depicted in Figure 5.

Figure 8 is of the same specimen using the overdriven recorder mode. The time base is 1 min/cm while the voltage scale is 5V/div. $\tau$ was calculated to be 2.66 minutes with a projected time to zero of 13.3 minutes. Note the drastic difference in decay rates between this and Figure 3. The two specimens were ostensibly the same except for the presence of the conductors in the "SWKW" coded material. A much shorter resistance path to ground is plainly evidenced.

Figures 9 through 13 were recorded during tests of the triboelectric fixture with some rather interesting results. Note that a definite decay curve is displayed, particularly when very high charges were achieved. This could be attributed to the corona effects that occur at extremely high voltages around sharp edges and projections. However, a phenomenon observed in Figures 12 and 13 tends to indicate otherwise.

Figure 9 was recorded from a factory-fresh specimen of the fabric coded "NWNN". All factory-applied sizing is in place. An initial peak charge of 18,500 volts is indicated as the rubbing wheel moved away from the specimen. This charge rapidly depleted, leveling off at around 2,500 volts.

Figure 10 represents a similar specimen that had been lightly rinsed in perchlorethylene. Only a slight difference can be noted.

Figure 11 was recorded from a specimen of NWNN that had been treated with a topical antistat by a dry-cleaning establishment that specializes in such procedures. Note that the peak measuring 6,375 volts was considerably less than that of the two previous specimens.

Figure 12 displays a completely unexpected phenomenon. This was recorded from a factory fresh specimen of the camouflage fabric discussed earlier. The peak voltage measured only 2500 volts when it was fully expected to act similarly to those depicted in Figures 9 and 10. Considerable thought resulted in the theory that the presence of the conductors in the specimen almost instantly coupled the available charge over to the specimen holder, equalizing that charge over the entire holder/specimen assembly.

This could also explain to some extent the steep though quite readable curves in Figures 9 through 11 since the fabric charges in those instances would have more difficulty in transferring to the holders. It can be assumed that the curve exists in Figure 12 but is so steep as to be beyond the capabilities of the recording device.

Figure 13 was recorded from a specimen of factory fresh fabric about which it is only known to have conductive content. The recording was made to verify the phenomenon indicated in Figure 12. This chart tentatively verifies that Figure 12 was not simply an aberration. Further experiments will be performed to ascertain the exact cause of this characteristic.

6. BLUEPRINTS AND SCHEMATIC DIAGRAMS:

The generation of blueprints covering the triboelectric test fixture and of schematic diagrams to document the changes to existing test equipments and new control circuitry necessary for completion of this project have not yet been finalized. This is due to the fact that the triboelectric fixture is still awaiting certain parts, and the various new control circuits are in a state of flux as minor aberrations are discovered and corrected.

Master Drawings, after completion and final approval, become the property of and are handed over to the the sponsoring activity. It then becomes extremely difficult to obtain these Masters when revisions are necessary. Since only the Masters can legally be revised, it is advisable to delay generation of such Master Drawings until such time as the proper operation of all equipment has been thoroughly proven. It is expected that the tests, experiments and circuit changes necessary for this activity will consume a considerable amount of time during Phase II of this project. The delays in providing the above mentioned Master Drawings are in the interests of economy and of avoiding unnecessary duplication of detailed and difficult artwork.

7. RESULTS:

With the exception of complete and thorough documentation of the triboelectric test fixture, modifications to the 406C and necessary external control circuitry, all objectives of the Phase I proposal for this project have been met as follows:

(a) Except for a few minor commercial parts still on order, the triboelectric tester has been designed, fabricated and proven to perform as expected. This apparatus, in conjunction with a properly modified 406C Static Decay Meter, is capable of characterizing the electrostatic charge-generating property of a fabric or other material when such is rubbed by a sample of itself or some other selected material. Peak voltages generated are recorded on chart paper, and the recordings are then available for detailed analysis and inclusion in reports and other documentation.

(b) The controlled humidity test chamber Model 506 has been so modified as to provide a test environment of less than 1% RH without the use of dry nitrogen. Further, an air circulation system has been mounted within the chamber to circulate ionized internal air.

(c) The 406C Static Decay Meter and its decay time test fixture have been modified to improve accuracy and broaden their capabilities. Further, the modified 406C instrument is now capable of accepting signals from the triboelectric test fixture and outputting these signals to an appropriate chart recorder.

(d) A special memory conditioning circuit has been incorporated into the test console to provide a usable signal from the M-2050 to a chart recorder, when measured events occur too rapidly for the relatively slow electro-mechanical components of the recorder to respond. By this means, events as short as 1 ms in width can be stored in the M-2050's memory and then recorded on the chart during a one-minute interval, well within the capabilities of most chart recorders. Front-panel adjustments allow maximum utilization of chart paper width for purposes of analyzing presented data.

8. CONCLUSIONS AND RECOMMENDATIONS:

From the information presented above, it can be concluded that it is entirely feasible to perform tests that will characterize the inherent field suppression, electrostatic charge decay, and triboelectric charge generating properties of nonhomogeneous fabrics and other materials utilizing a minimum of equipment. The necessary apparatus has already been modified and/or designed and prototyped for this purpose.

It is therefore highly recommended that Phase II of this project be implemented for purposes of completing the necessary documentation including the actual generation of standardized test methods for future use by both the Government and the Private Sector.

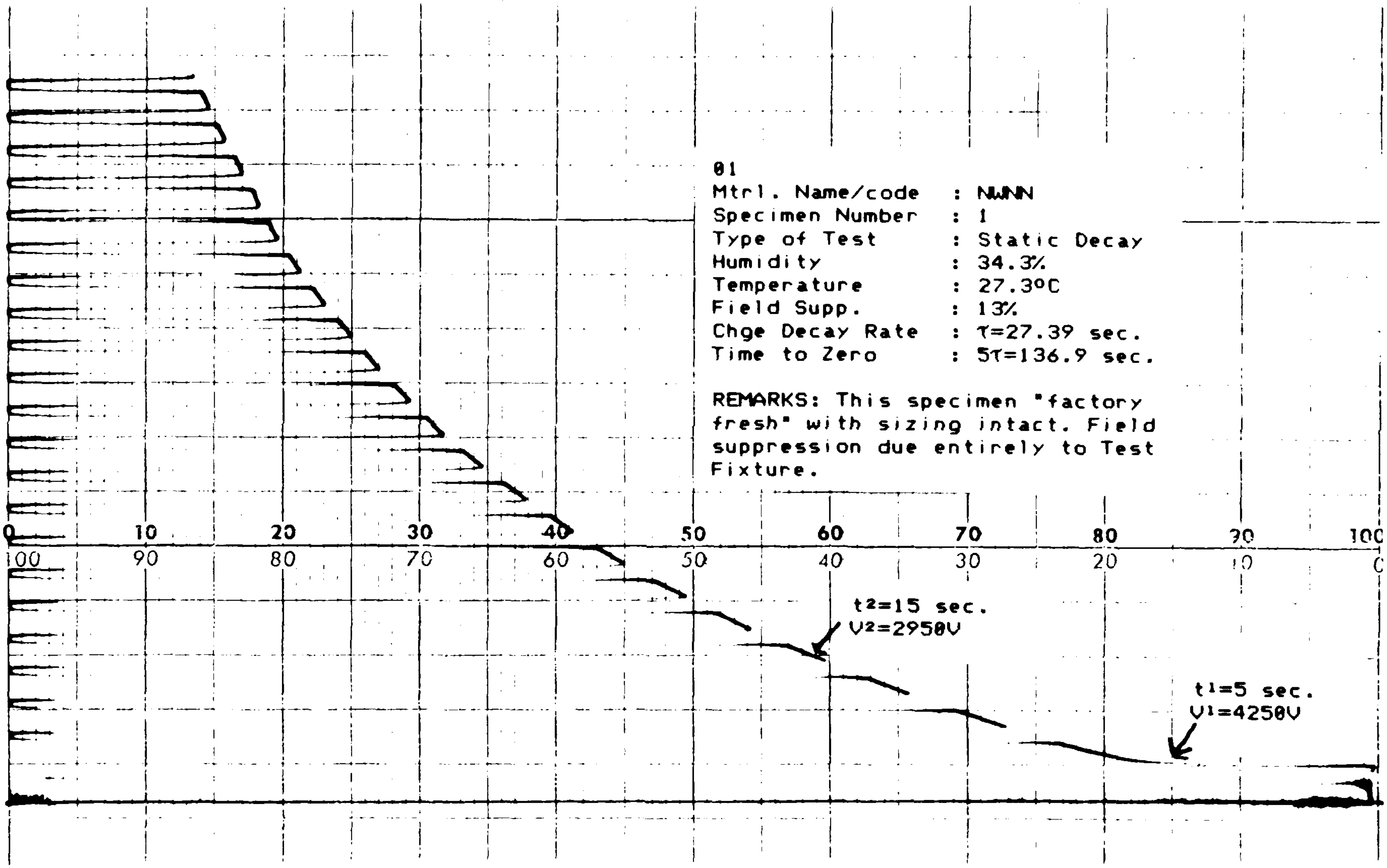


Figure 1. <u>Static decay test of factory-fresh control fabric.</u>

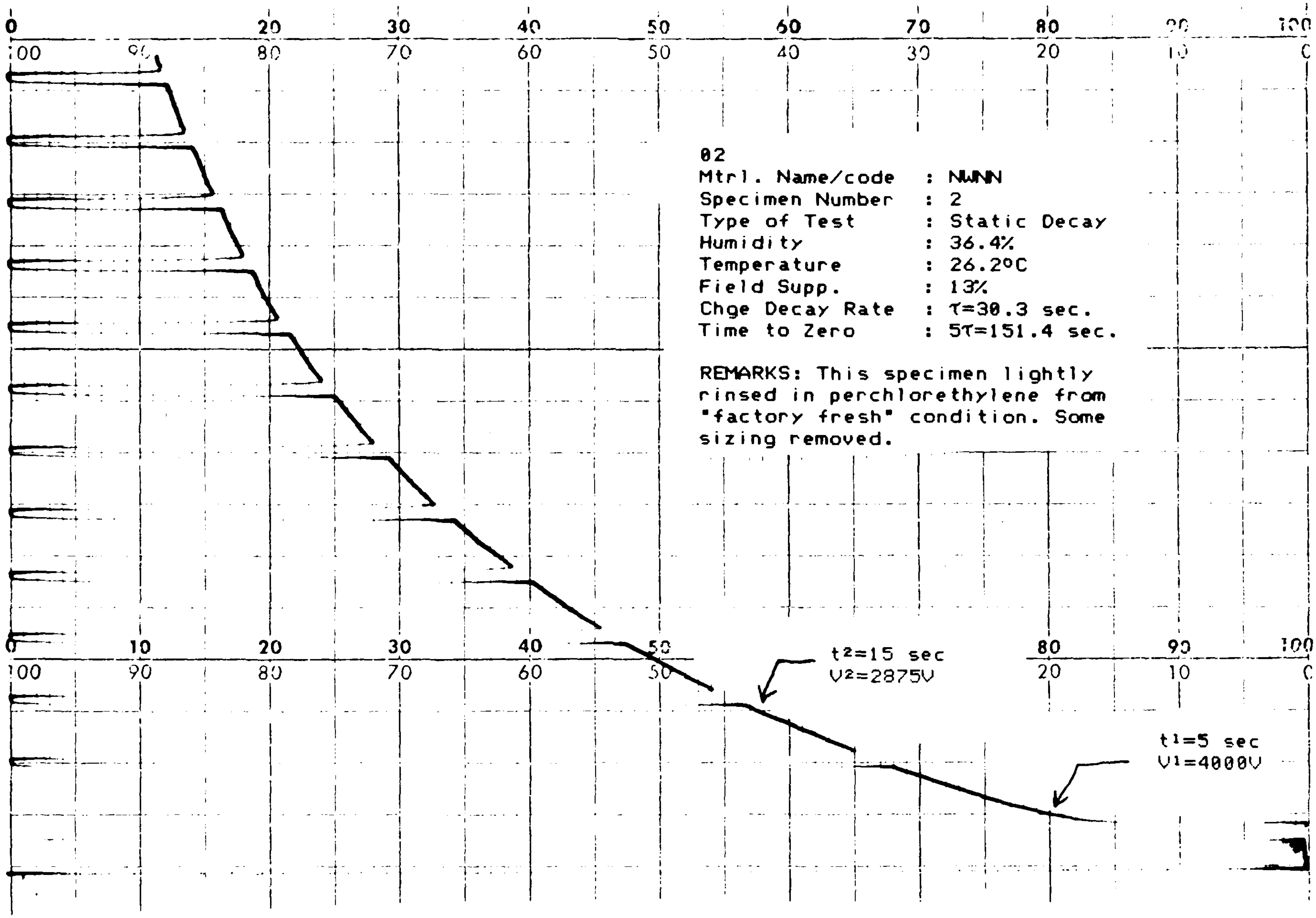


Figure 2. Static decay test of control fabric after rinse in perchlorethylene.

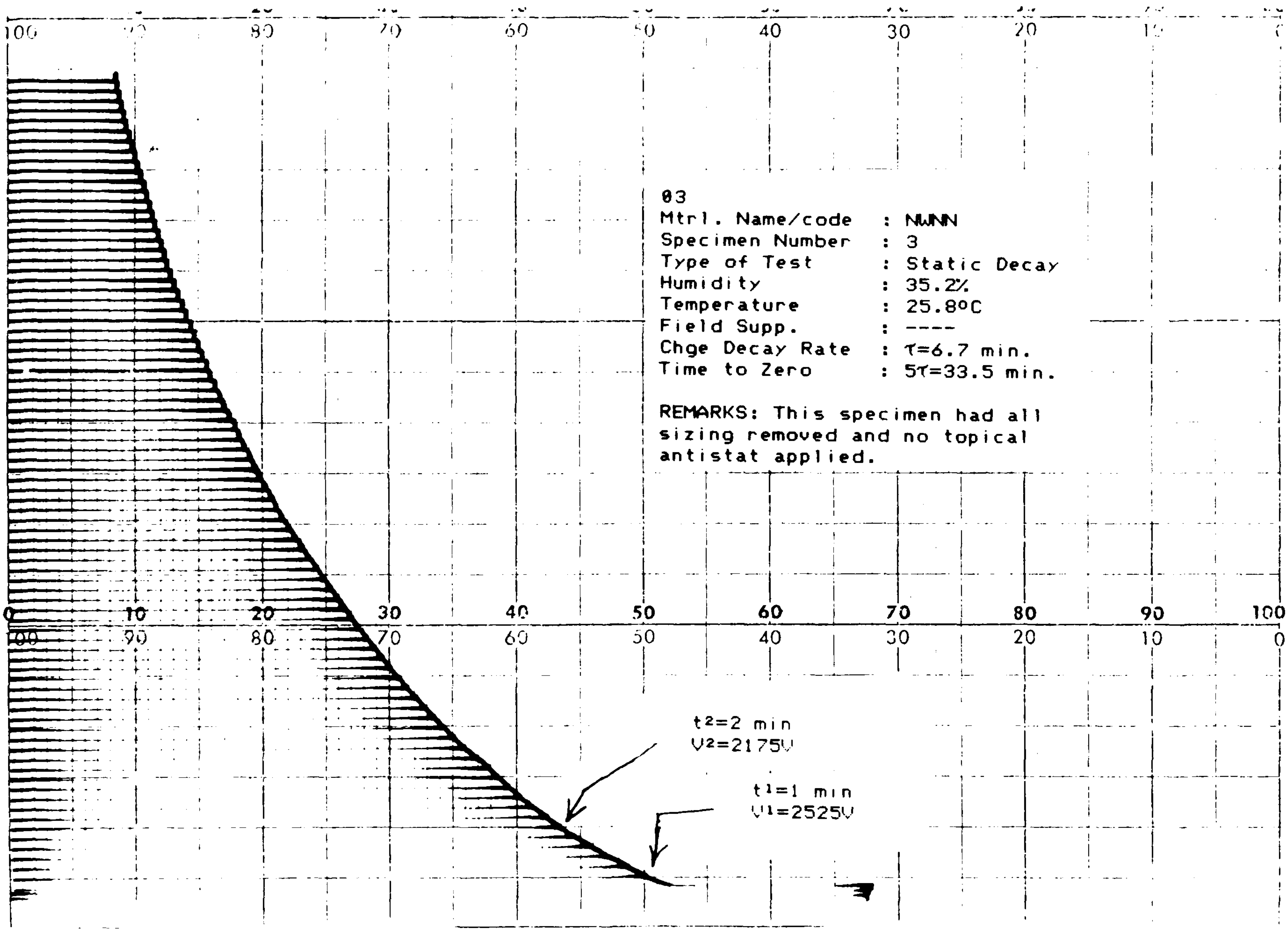


Figure 3. Static decay test of control fabric with no sizing or topical antistat.

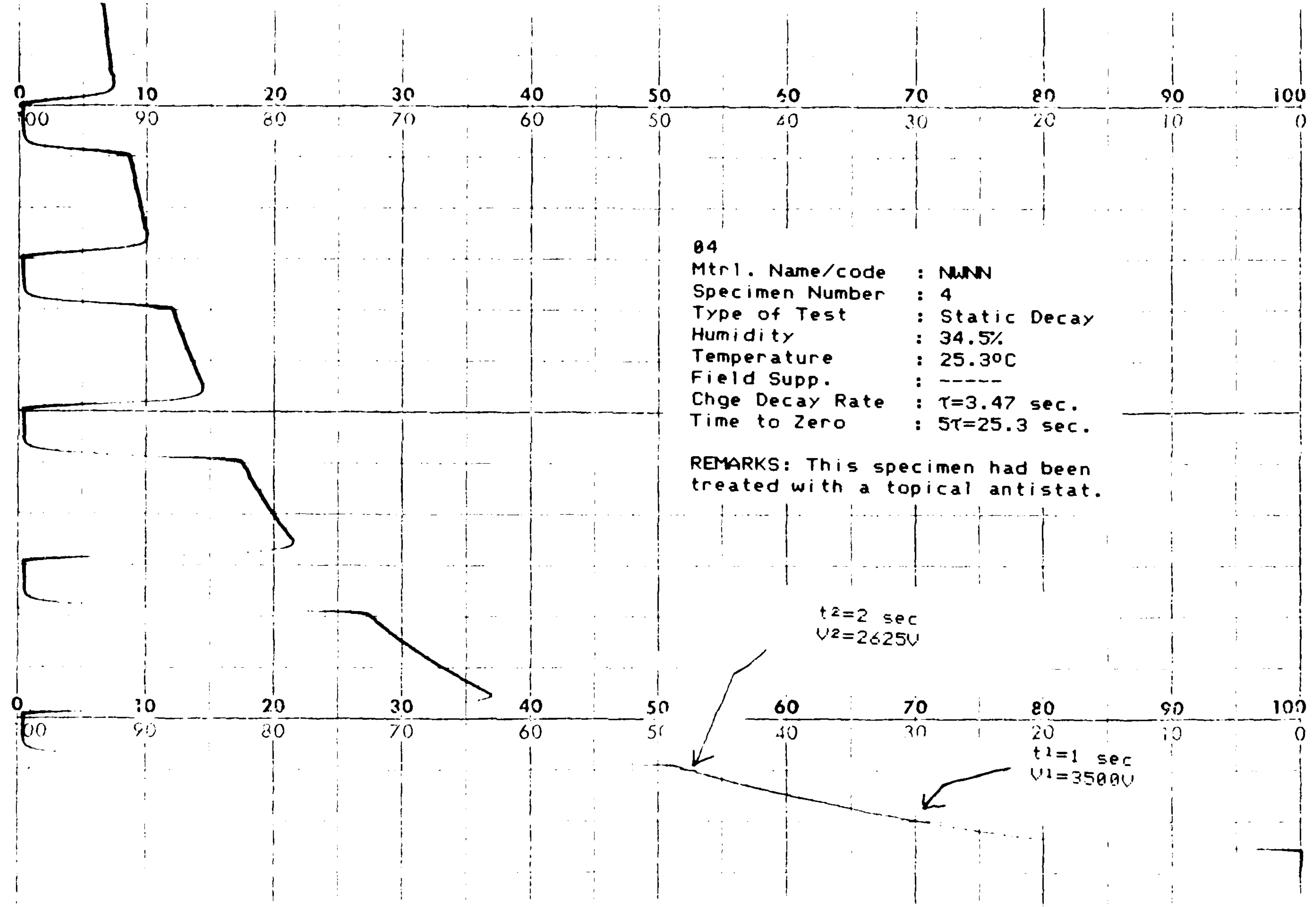


Figure 4. Static decay test of control fabric with topical antistat applied.

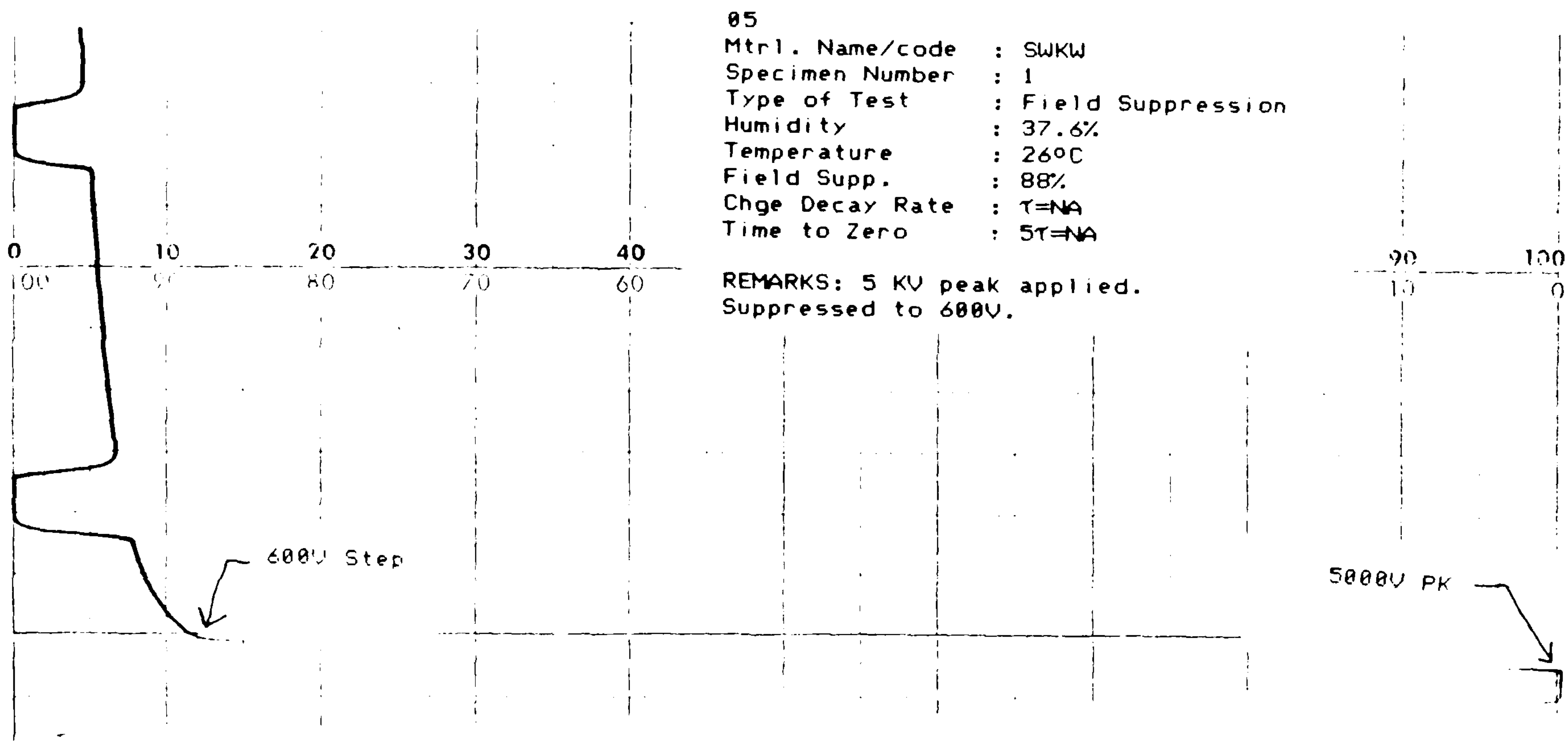


Figure 5. <u>Field-suppression test of fabric containing 1% stainless steel.</u>

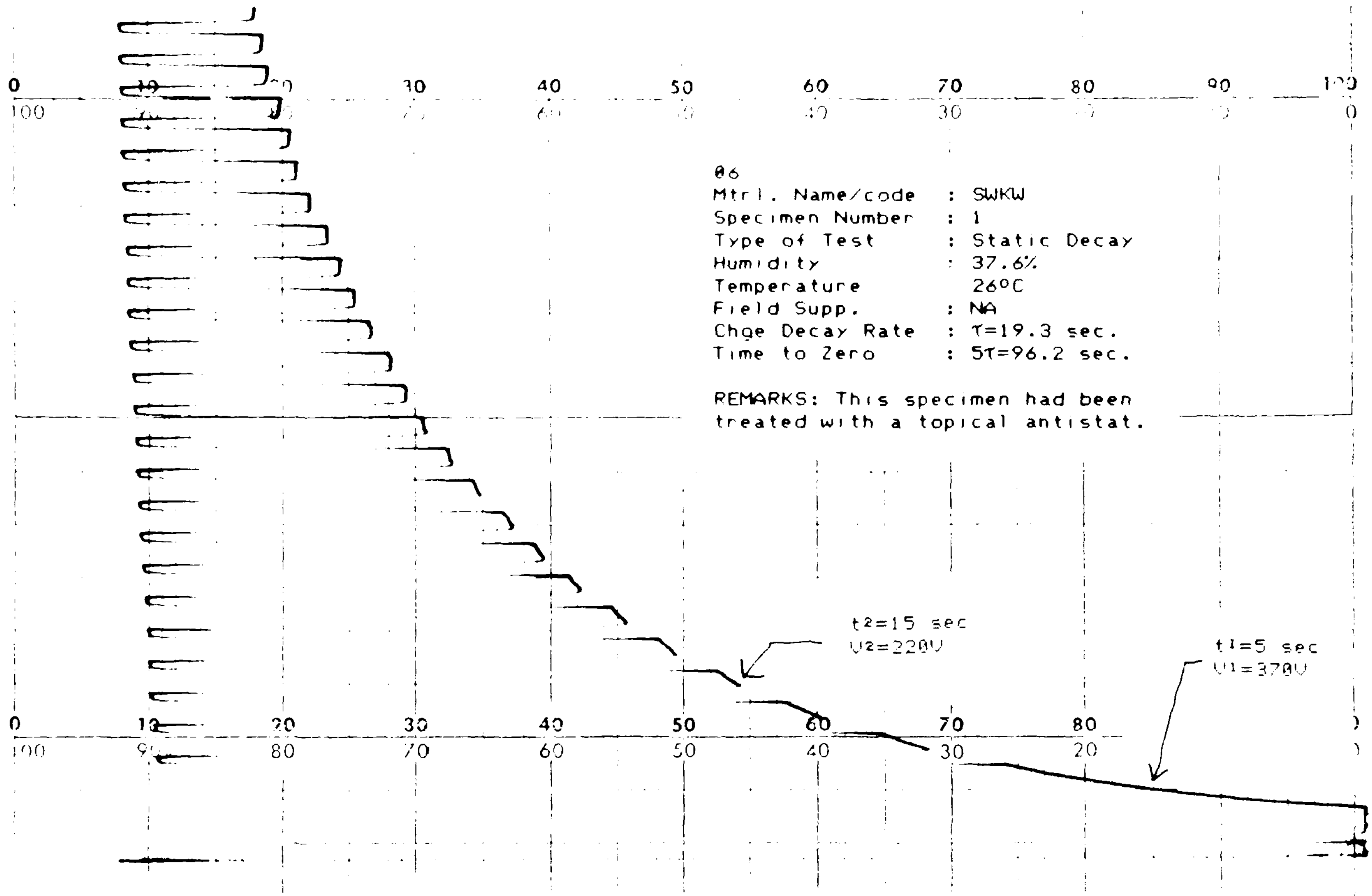


Figure 6. Static decay test of fabric containing 1% stainless steel and topical antistat.

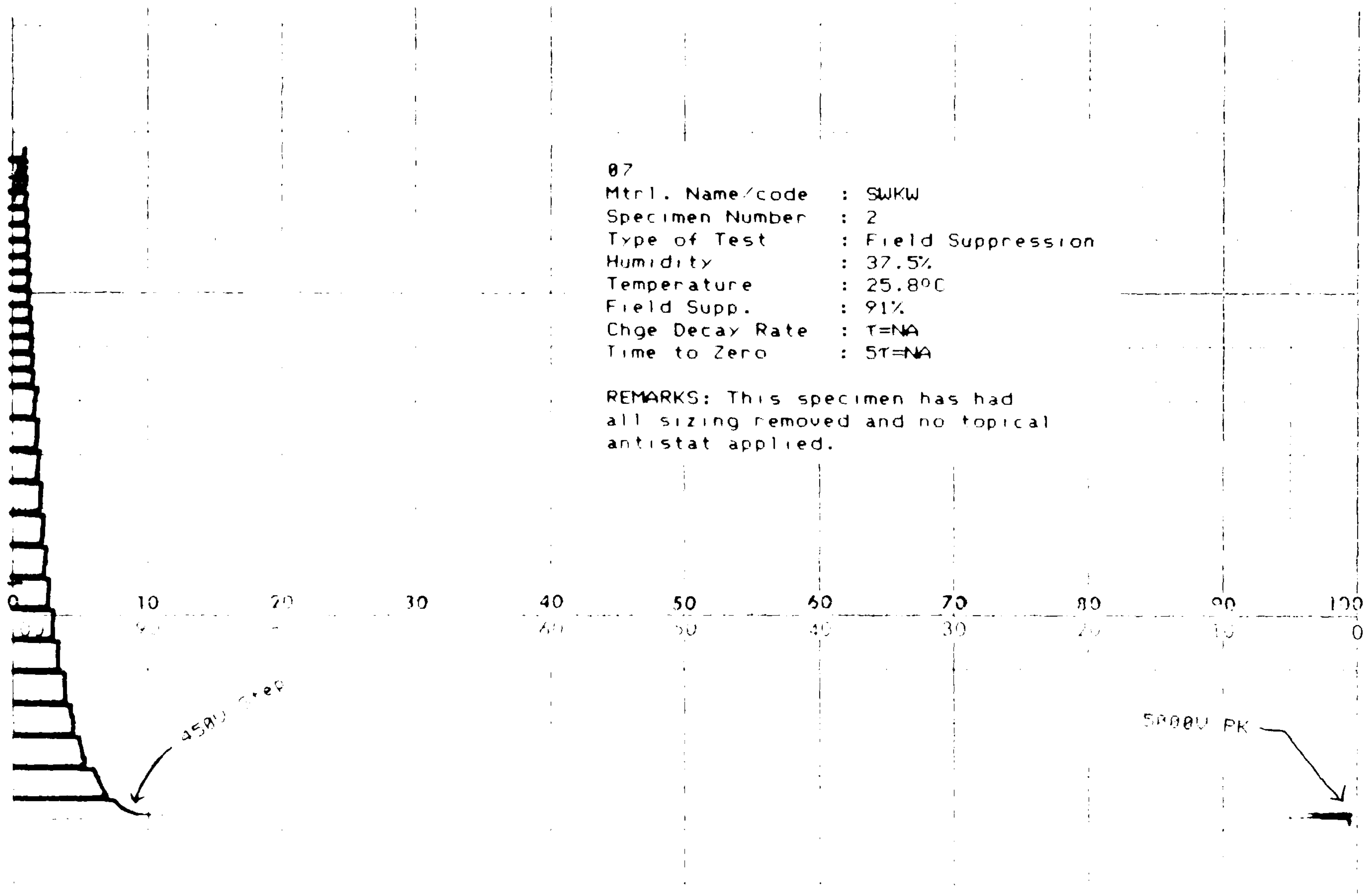


Figure [illegible]. Field-suppression test of fabric containing 1% stainless steel, no sizing or topical antistat.

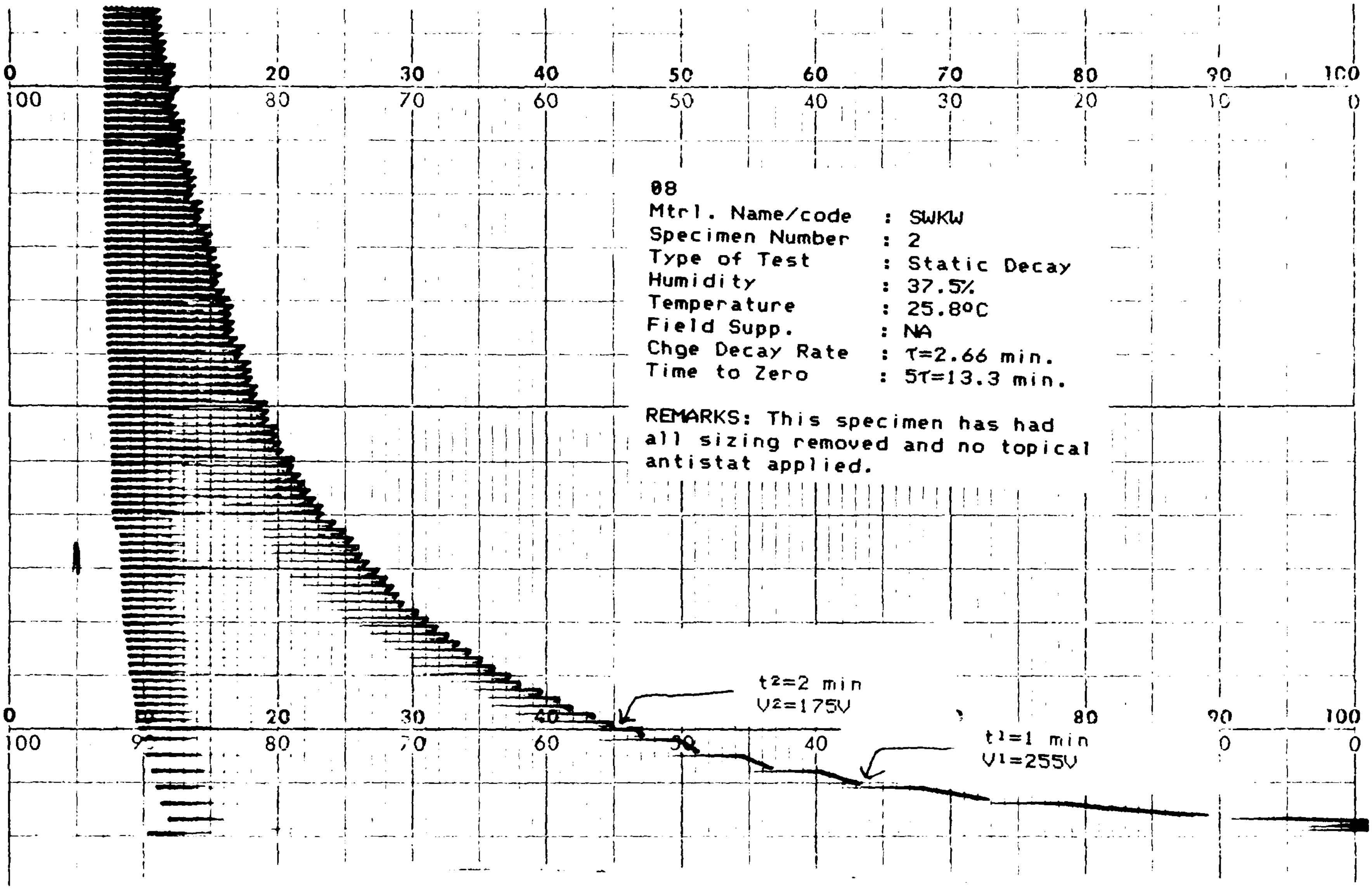


Figure 8. Static decay test of fabric containing 1% stainless steel, no sizing or topical antistat.

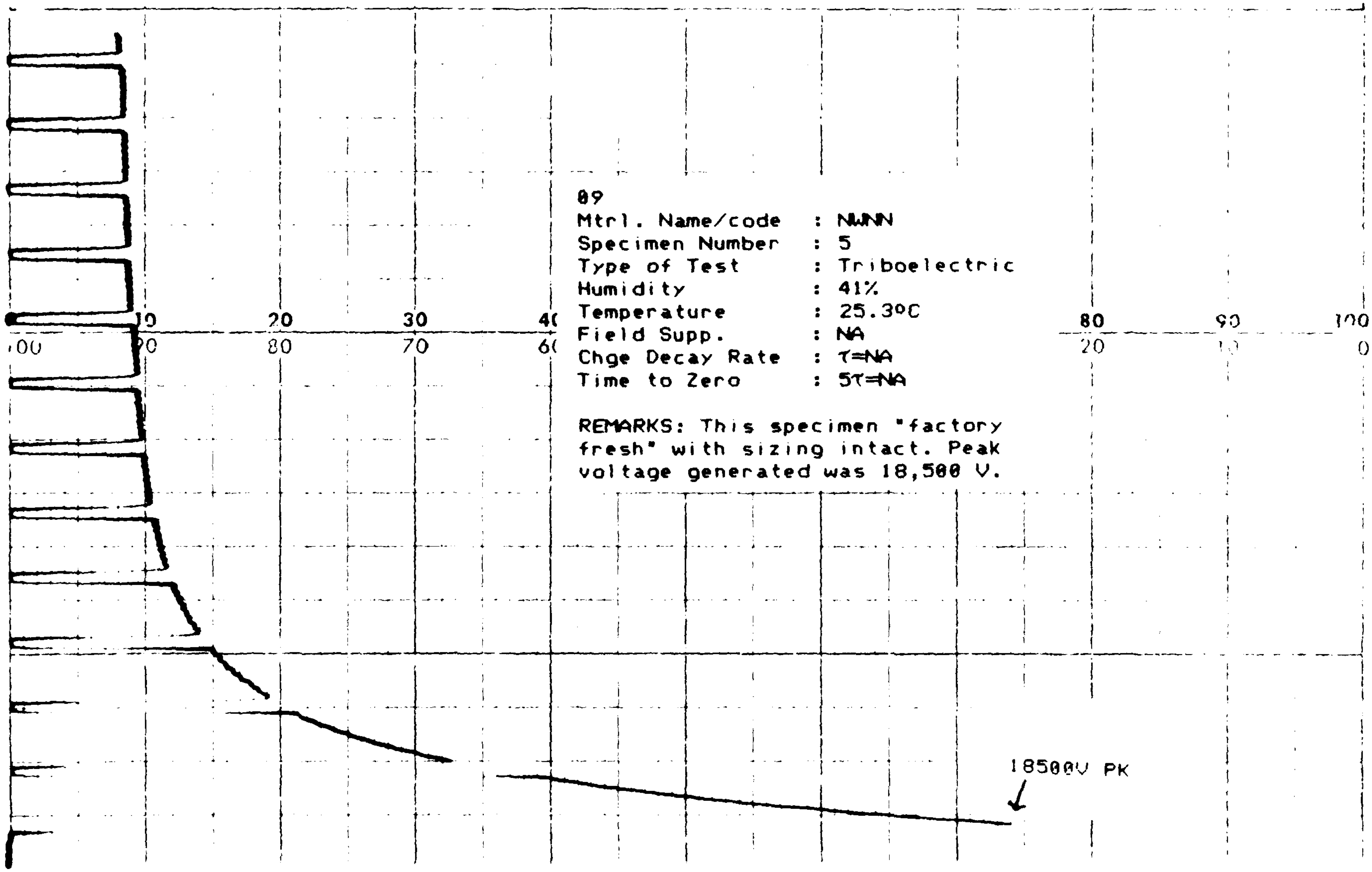


Figure 9. Triboelectric test of factory-fresh control fabric with all sizing intact.

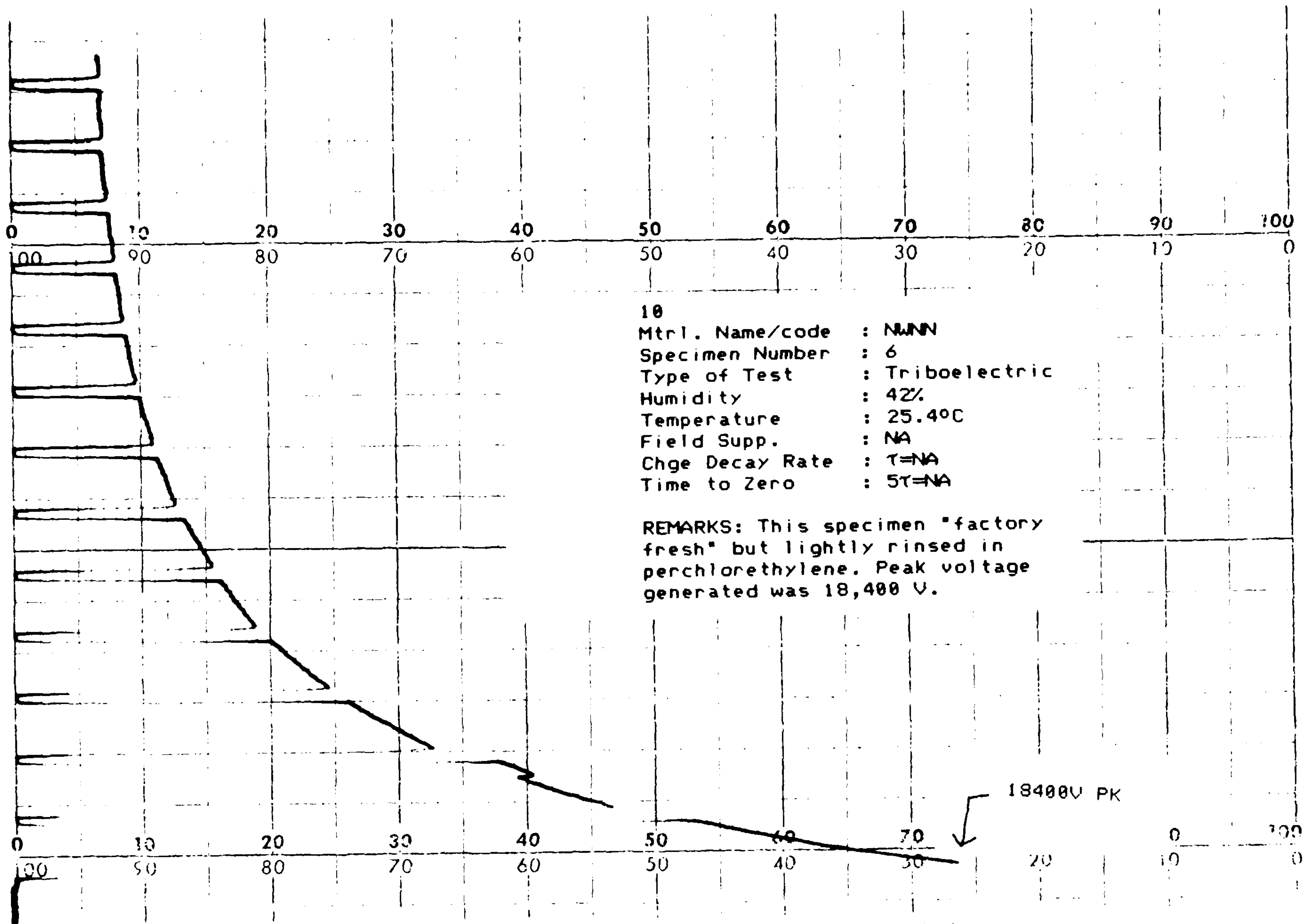


Figure10. Triboelectric test of control fabric rinsed in perchlorethylene.

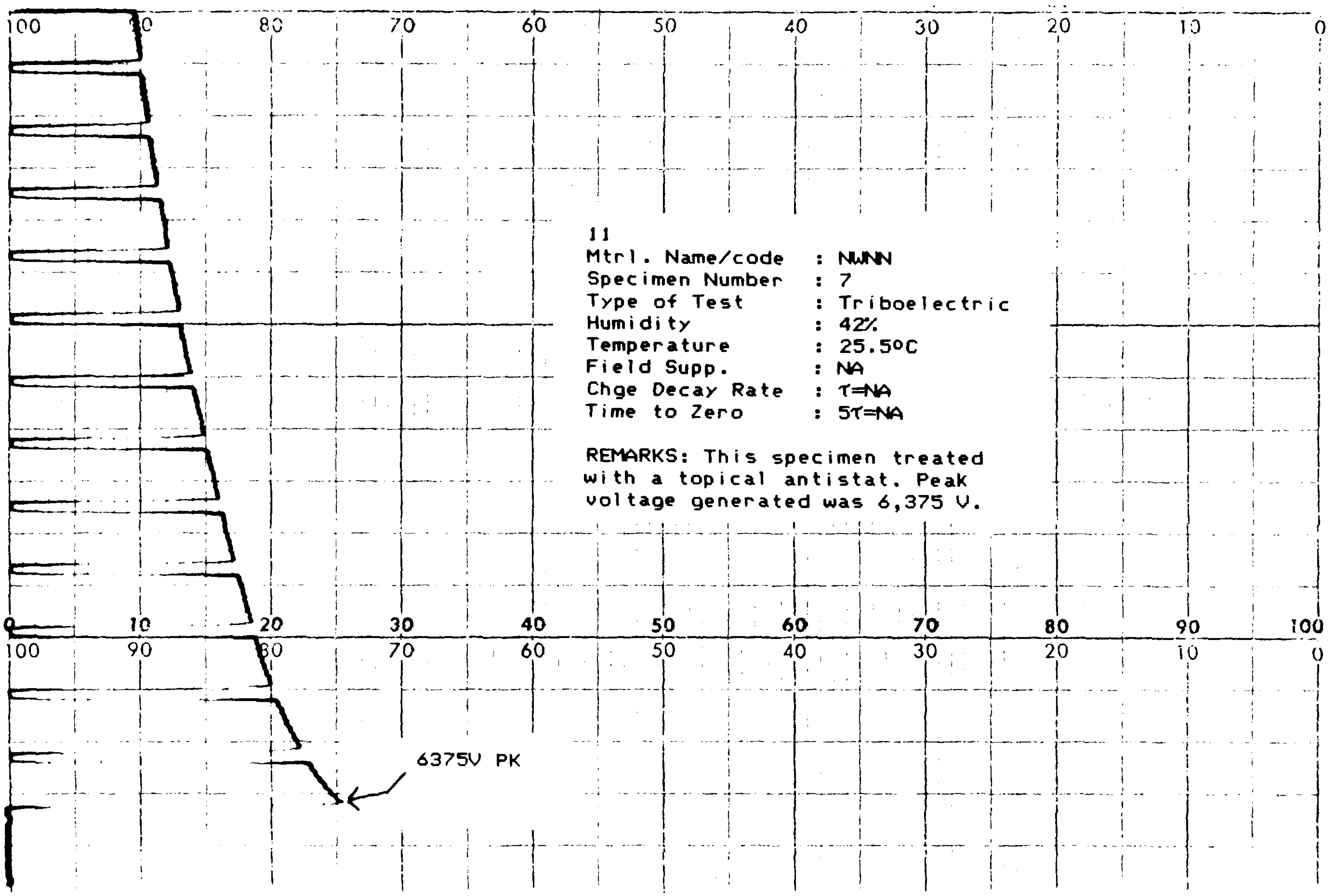


Figure 11. <u>Triboelectric test of control fabric treated with topical antistat.</u>

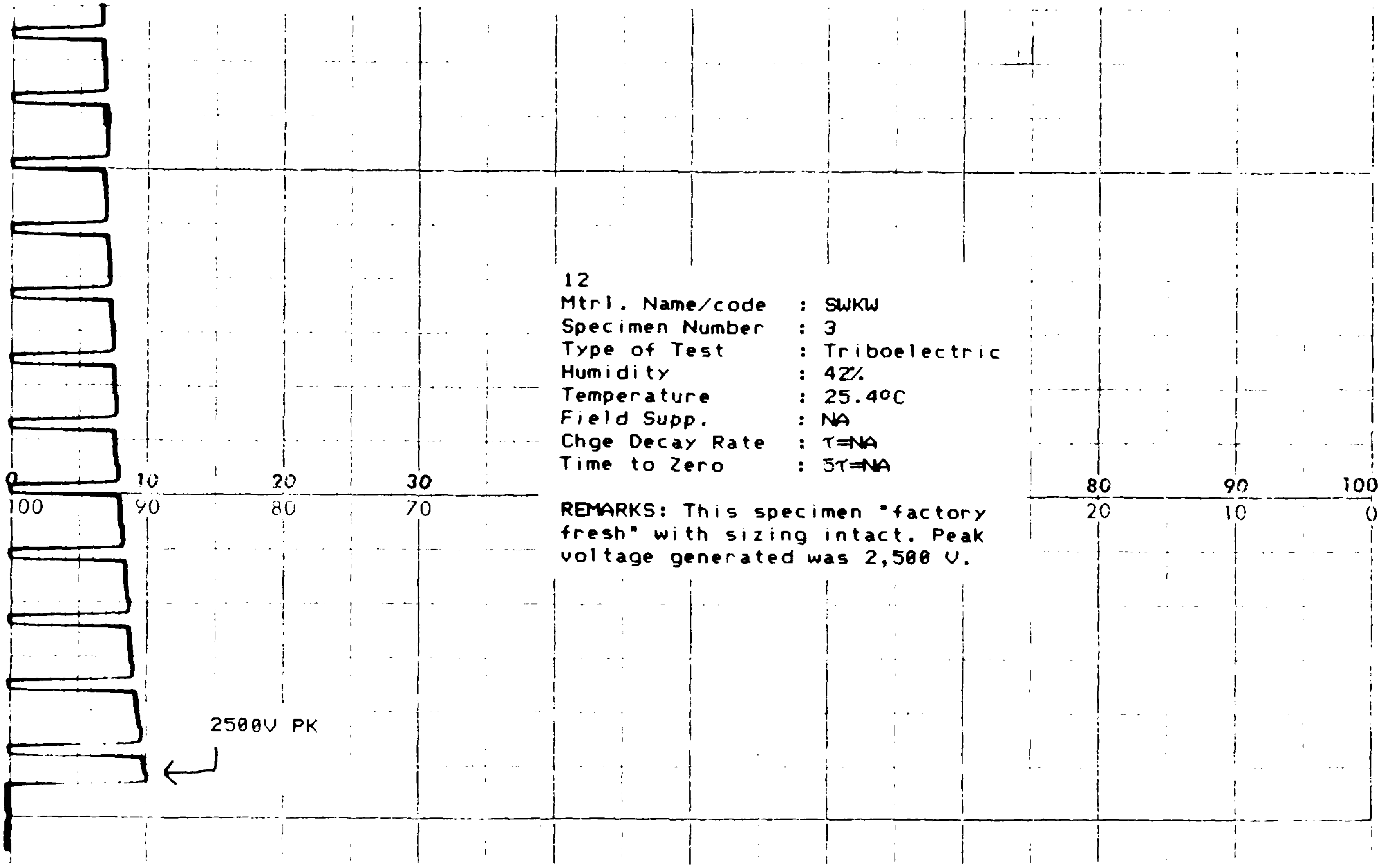


Figure 12. Triboelectric test of factory-fresh fabric containing 1% stainless steel.

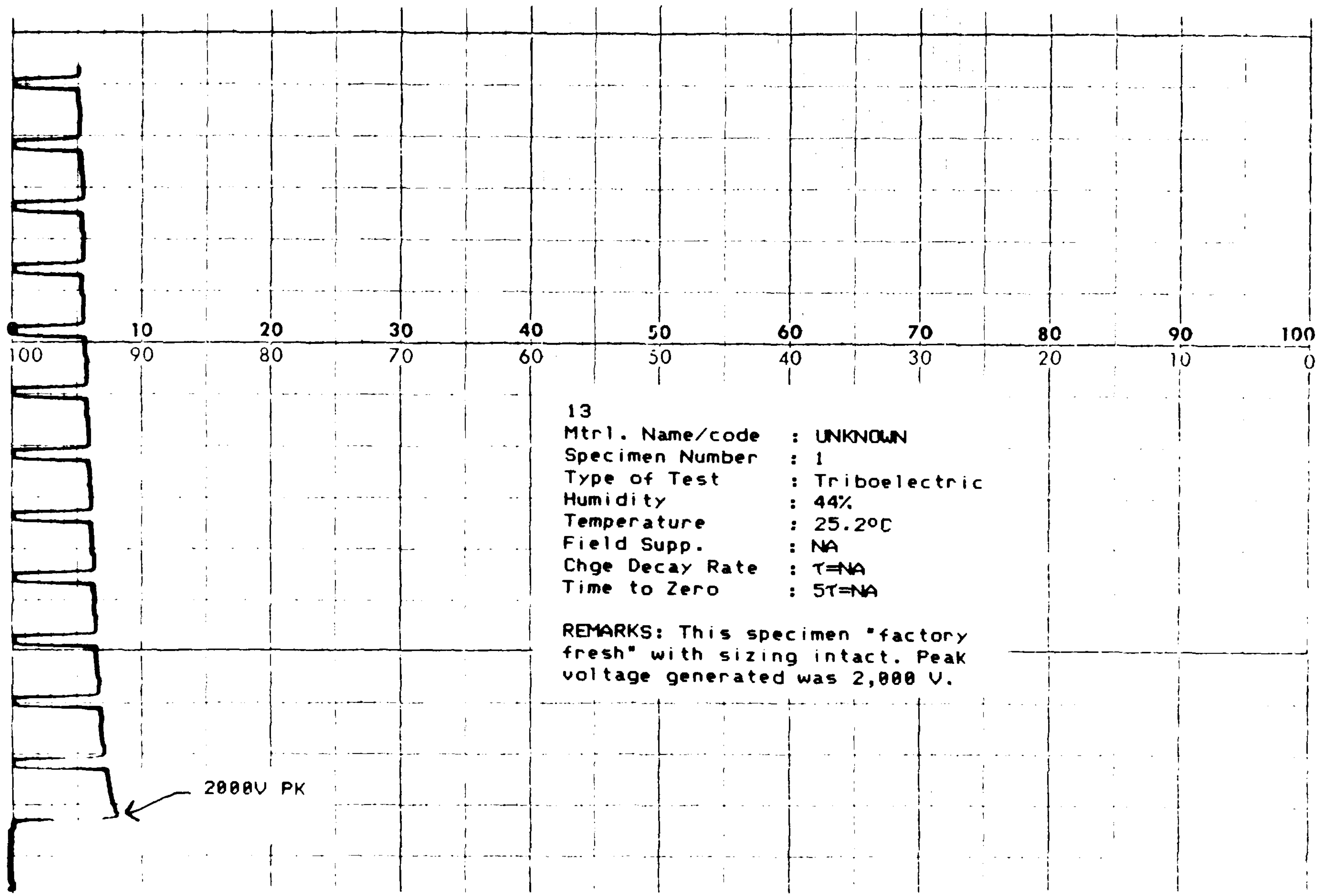


Figure 13. Triboelectric test of factory-fresh fabric with conductive material, percentage unknown.

## LIST OF REFERENCES

1. Federal Test Method Standard No. 101, Method 4046: "Electrostatic Properties of Materials".